

1. <i>Chlorophyll content</i>	
Sample	Value
1.1	0.15
1.2	0.15
1.3	0.15
1.4	0.15
1.5	0.15
1.6	0.15
1.7	0.15
1.8	0.15
1.9	0.15
1.10	0.15
1.11	0.15
1.12	0.15
1.13	0.15
1.14	0.15
1.15	0.15
1.16	0.15
1.17	0.15
1.18	0.15
1.19	0.15
1.20	0.15
1.21	0.15
1.22	0.15
1.23	0.15
1.24	0.15
1.25	0.15
1.26	0.15
1.27	0.15
1.28	0.15
1.29	0.15
1.30	0.15
1.31	0.15
1.32	0.15
1.33	0.15
1.34	0.15
1.35	0.15
1.36	0.15
1.37	0.15
1.38	0.15
1.39	0.15
1.40	0.15
1.41	0.15
1.42	0.15
1.43	0.15
1.44	0.15
1.45	0.15
1.46	0.15
1.47	0.15
1.48	0.15
1.49	0.15
1.50	0.15
1.51	0.15
1.52	0.15
1.53	0.15
1.54	0.15
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1.57	0.15
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1.71	0.15
1.72	0.15
1.73	0.15
1.74	0.15
1.75	0.15
1.76	0.15
1.77	0.15
1.78	0.15
1.79	0.15
1.80	0.15
1.81	0.15
1.82	0.15
1.83	0.15
1.84	0.15
1.85	0.15
1.86	0.15
1.87	0.15
1.88	0.15
1.89	0.15
1.90	0.15
1.91	0.15
1.92	0.15
1.93	0.15
1.94	0.15
1.95	0.15
1.96	0.15
1.97	0.15
1.98	0.15
1.99	0.15
2.00	0.15
2.01	0.15
2.02	0.15
2.03	0.15
2.04	0.15
2.05	0.15
2.06	0.15
2.07	0.15
2.08	0.15
2.09	0.15
2.10	0.15
2.11	0.15
2.12	0.15
2.13	0.15
2.14	0.15
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2.23	0.15
2.24	0.15
2.25	0.15
2.26	0.15
2.27	0.15
2.28	0.15
2.29	0.15
2.30	0.15
2.31	0.15
2.32	0.15
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2.34	0.15
2.35	0.15
2.36	0.15
2.37	0.15
2.38	0.15
2.39	0.15
2.40	0.15
2.41	0.15
2.42	0.15
2.43	0.15
2.44	0.15
2.45	0.15
2.46	0.15
2.47	0.15
2.48	0.15
2.49	0.15
2.50	0.

## OLEDS HAVING LIGHT ABSORBING ELECTRODE

**OLEDs HAVING LIGHT ABSORBING ELECTRODE**

**BACKGROUND OF THE INVENTION**

Organic light emitting devices (OLEDs) represent a promising technology for display applications. A typical organic light emitting device includes a transparent first electrode, which usually acts as a hole-injecting anode; a luminescent region comprising one or more electroluminescent organic layer(s); and a second electrode (also called a "back electrode"), which usually acts as an electron-injecting cathode. In order to facilitate electron injection from the back electrode into the electroluminescent layer(s), the back electrode generally is formed of a low work function metal, and therefore is highly reflective. When a voltage is applied across the first and second electrodes, light is emitted from the electroluminescent layer(s) and through the transparent anode. When viewed under high ambient illumination, the reflective back electrode reflects a substantial amount of the ambient illumination to the observer, which results in higher ratios of reflected illumination as compared to the device's own emission, which results in "washout" of the displayed image.

In order to improve the contrast of electroluminescent displays in general, light absorbing layers as described, for example, in U.S. Patent 4,287,449, or optical interference members as described, for example, in U.S. Patent 5,049,780, have been used to reduce the ambient illumination reflection. Both of these approaches involve the use of optical films made of materials that are generally non-conductive. These properties limit the applicability of such materials to organic light emitting devices, which, unlike inorganic electroluminescent phosphor devices, require the direct injection of charges from the electrodes to the electroluminescent layer(s). In addition, the fabrication of such optical films, essentially from dielectric inorganic materials, often requires the use of sputtering or electron beam evaporation techniques. These fabrication techniques require additional instrumentation to be incorporated into the otherwise relatively simple fabrication process of organic light emitting devices by thermal evaporation or spin coating techniques. Also, in cases using optical interference effects for achieving improved contrast, such as disclosed, for example, in U.S. Patent 5,049,780, it is usually required to use more than one optical film in order to achieve the desired improvement, which is disadvantageous to the fabrication

process. Furthermore, the resulting improvement in display contrast is inevitably dependent on the viewing angle.

Thus, there is a need, addressed by the present invention, for new OLEDs that avoid or minimize a number of the disadvantages described above for conventional electroluminescent devices.

Organic light emitting devices are disclosed in the following:

Pending US Serial No. 09/800,716 (titled "cathodes for electroluminescent devices having improved contrast and reduced dark spot growth"), assigned to Xerox Corporation; and

O. Renault et al., "A low reflectivity multilayer cathode for organic light-emitting diodes," *Thin Solid Films*, Vol. 379, pp. 195-198 (December 8, 2000);

International Application Publication No. WO 01/08240 A1; and

David Johnson et al., "Contrast Enhancement of OLED Displays," [http://www.luxell.com/pdfs/OLED\\_tech\\_ppr.pdf](http://www.luxell.com/pdfs/OLED_tech_ppr.pdf), pp. 1-3 (April 2001).

## **SUMMARY OF THE INVENTION**

The present invention is accomplished in embodiments by providing an organic light emitting device comprising:

a first electrode;

a second electrode; and

a luminescent region including an organic electroluminescent material between the first electrode and the second electrode, wherein one of the first electrode and the second electrode includes both a substantially transparent charge injecting layer adjacent to the luminescent region and an electrically conductive light absorbing layer.

There is also provided in embodiments an organic light emitting device comprising in sequence:

(a) a cathode including:

(i) an electrically conductive light absorbing layer, and

(ii) a substantially transparent electron injecting layer;

(b) a luminescent region including an organic electroluminescent material; and

(c) an anode that is substantially transparent to light.

There is provided in additional embodiments an organic light emitting device comprising in sequence:

(a) a cathode that is substantially transparent to light;

(b) a luminescent region including an organic electroluminescent material; and

1 (c) an anode including:

2 (i) a substantially transparent hole injecting layer, and

3 (ii) an electrically conductive light absorbing layer.

4  
5 **BRIEF DESCRIPTION OF THE DRAWINGS**

6  
7 Other aspects of the present invention will become apparent as the following  
8 description proceeds and upon reference to the Figures which represent illustrative  
9 embodiments:

10 FIG. 1 is a schematic, elevational view in cross-section of a first embodiment of  
11 the present OLED;

12 FIG. 2 is a schematic, elevational view in cross-section of a second embodiment  
13 of the present OLED;

14 FIG. 3 is a schematic, elevational view in cross-section of a third embodiment of  
15 the present OLED; and

16 FIG. 4 is a schematic, elevational view in cross-section of a fourth embodiment  
17 of the present OLED.

18 Unless otherwise noted, the same reference numeral in different Figures refers to  
19 the same or similar feature.

20  
21 **DETAILED DESCRIPTION**

22  
23 The present organic light emitting device is composed of at least a first  
24 electrode; a second electrode; and a luminescent region including an organic  
25 electroluminescent material between the first electrode and the second electrode,  
26 wherein one of the first electrode and the second electrode includes both a substantially  
27 transparent charge injecting layer adjacent to the luminescent region and an electrically  
28 conductive light absorbing layer. Either the cathode or the anode can include the  
29 charge injecting layer and the electrically conductive light absorbing layer. The charge  
30 injecting layer may be either an electron injecting layer (in the case of a cathode) or a  
31 hole injecting layer (in the case of an anode). The present organic light emitting device  
32 may include a substrate either as a separate layer adjacent to one of the electrodes or  
33 incorporated into one of the electrodes (e.g., the electrically conductive light absorbing  
34 layer that is part of an electrode includes in embodiments a substrate material to result  
35 in an electrically conductive light absorbing substrate).

A first exemplary embodiment is seen in FIG. 1 where the organic light emitting device 2A is composed of in the depicted sequence: a substrate 4A; an anode 6A; a luminescent region 8A; and a cathode 10A including a substantially transparent electron injecting layer 12A, an optional buffer layer 14A, an electrically conductive light absorbing layer 16A, and an optional metallic layer 18A. In FIG. 1, the anode 6A and substrate 4A are substantially transparent so that light emitted within the luminescent region can reach the viewer.

As used herein, the phrase “substantially transparent” indicates a significant level of light transmissivity through a layer such as for example at least about 50% transmissivity, particularly at least about 70% transmissivity.

A second exemplary embodiment is seen in FIG. 2 where the organic light emitting device 2B is composed of in the depicted sequence: an anode 6B; a luminescent region 8B; and a cathode 10B including a substantially transparent electron injecting layer 12B, an optional buffer layer 14B, an electrically conductive light absorbing layer 16B, and an optional metallic layer 18B; and a substrate 4B. In FIG. 2, the anode 6B is substantially transparent so that light emitted within the luminescent region can reach the viewer.

A third exemplary embodiment is seen in FIG. 3 where the organic light emitting device 2C is composed of in the depicted sequence: a substrate 4C; a cathode 10C; a luminescent region 8C; and an anode 6C including a substantially transparent hole injecting layer 12C, an optional buffer layer 14C, an electrically conductive light absorbing layer 16C, and an optional metallic layer 18C. In FIG. 3, the cathode 10C and substrate 4C are substantially transparent so that light emitted within the luminescent region can reach the viewer.

A fourth exemplary embodiment is seen in FIG. 4 where the organic light emitting device 2D is composed of in the depicted sequence: a cathode 10D; a luminescent region 8D; and an anode 6D including a substantially transparent hole injecting layer 12D, an optional buffer layer 14D, an electrically conductive light absorbing layer 16D, and an optional metallic layer 18D; and a substrate 4D. In FIG. 4, the cathode 10D is substantially transparent so that light emitted within the luminescent region can reach the viewer.

FIGS. 1-4 depict a single light absorbing layer. In other embodiments, however, two or more light absorbing layers may be present.

The reason for improved contrast by the present invention is now discussed. The incorporation of a substantially transparent charge injecting layer (12A, 12B, 12C,

12D) results in the transmission of a substantial portion of ambient light reaching this layer, and therefore, the portion of ambient light that is reflected back from this layer to the viewer is substantially reduced. Furthermore, the incorporation of an electrically conductive light absorbing layer (16A, 16B, 16C, 16D) absorbs a substantial portion of the ambient light that is transmitted through the charge injecting layer (and the optional buffer layer), and therefore, a substantial portion of the ambient light that reaches the optional metallic layer is not reflected back to the viewer, and hence image washout is substantially reduced.

The amount of light absorption of the light absorbing layer depends on the extinction coefficient of the light absorbing material comprising the light absorbing layer, as well as on the thickness of the light absorbing layer, where, in general, a higher value for the extinction coefficient and a larger layer thickness lead to more light absorption, and hence are more desirable in embodiments. Also, the higher the extinction coefficient of the material, the less the thickness needed to achieve a certain amount of light absorption.

The multi-layer electrode of the present OLED (having the charge injecting layer and the electrically conductive light absorbing layer) exhibits as a whole both lateral electrical conductivity (across the width of the electrode) and cross directional electrical conductivity (through the thickness of the electrode). However, in certain embodiments, a layer of the multi-layer electrode such as the optional buffer layer, may exhibit cross directional conductivity but not lateral conductivity. That each of the electrode layers is considered part of the electrode arises from the fact that each of (1) the charge injecting layer, (2) the electrically conductive light absorbing layer, and the (3) the optional protective metallic layer contribute to both lateral conduction and cross directional conduction. The optional buffer layer, being made of an insulative material, does not contribute to lateral conduction, but is considered part of the electrode because if the buffer layer is thin enough, it can sustain cross directional conduction. In embodiments of the present invention, the multi-layer electrode is a stack of adjacent layers where each layer exhibits a cross directional electrical conductivity with an ohmic resistance less than about 100 ohms, particularly less than about 10 ohms, and especially less than about 1 ohm.

A substantially transparent substrate can comprise various suitable materials including, for example, polymeric components, glass, quartz and the like. Suitable polymeric components include, but are not limited to polyesters such as MYLAR®, polycarbonates, polyacrylates, polymethacrylates, polysulfones, and the like. Other



and Li:Al alloys, comprised of, for example, from about 90 to 99 volume percent of Al, and from about 10 to about 1 volume percent of Li, and the like, having a thickness, for example, from about 10 Å to about 200 Å, and, particularly, from about 30 Å to about 100 Å. Other substantially transparent cathodes are disclosed in US Serial No. 09/800,716, cited earlier, and incorporated herein by reference in its entirety, such as cathodes comprising a layer, of thickness from about 100 Å to about 10,000 Å, and particularly from about 500 Å to about 5,000 Å, comprised of a metal, an organic material, and a third component which can be a metal, an organic material, or any other material. One embodiment is a cathode composed of a layer comprised of about 47.4 volume percent of Mg, about 5.2 volume percent of Ag, and about 47.4 volume percent of tris(8-hydroxyquinoline) aluminum (AlQ<sub>3</sub>). Additional suitable forms of substantially transparent cathodes are disclosed in U.S. Patent 5,703,436, which is incorporated herein by reference in its entirety.

The thickness of the substantially transparent cathode can range from about 10 Å to about 50,000 Å, with the preferred range depending on the optical constants of the cathode material. One illustrative range of cathode thickness is from about 30 Å to about 100 Å. Another illustrative range is from about 50 Å to about 500 Å. Of course, a thickness outside of this range can also be used.

A substantially transparent electron injecting layer can include very thin substantially transparent metallic layers, composed of a metal with a work function ranging from about 2 eV to about 4 eV, such as Mg, Ag, Al, Ca, In, Li and their alloys such as Mg:Ag alloys composed of, for example, from about 80 to 95 volume percent of Mg and about 20 to about 5 volume percent of Ag, and Li:Al alloys, composed of, for example, from about 90 to 99 volume percent of Al, and from about 10 to about 1 volume percent of Li, and the like, having a thickness, for example, from about 10 Å to about 200 Å, and, particularly, from about 30 Å to about 100 Å. Other substantially transparent electron injecting layers are disclosed in US Serial No. 09/800,716, cited earlier, and incorporated herein by reference in its entirety, such as a layer, of thickness from about 100 Å to about 10,000 Å, and particularly from about 500 Å to about 5,000 Å, comprised of a metal, an organic material, and a third component which can be a metal, an organic material, or any other material. One embodiment is a layer composed of about 47.4 volume percent of Mg, about 5.2 volume percent of Ag, and about 47.4 volume percent of tris(8-hydroxyquinoline) aluminum (AlQ<sub>3</sub>).

The thickness of a substantially transparent electron injecting layer can range from about 10 Å to about 50,000 Å, with the preferred range depending on the optical









1 The luminescent region is composed of an organic electroluminescent material.  
2 Electroluminescent materials include, for example, polyphenylenevinylenes such as  
3 poly(p-phenylenevinylene) PPV, poly(2-methoxy-5-(2-ethylhexyloxy)1,4-  
4 phenylenevinylene) MEHPPV and poly(2,5-dialkoxyphenylenevinylene) PDMeOPV,  
5 and other materials disclosed in U.S Patent 5,247,190, which is incorporated herein by  
6 reference in its entirety; polyphenylenes, such as poly(p-phenylene) PPP, ladder-poly-  
7 *para*-phenylene (LPPP), and poly(tetrahydropyrene) PTHP; and polyfluorenes, such as  
8 poly(9,9-di-n-octylfluorene-2,7-diyl), poly(2,8-(6,7,12,12-tetraalkylindenofluorene)  
9 and copolymers containing fluorenes such as fluorene-amine copolymers (see e.g.,  
10 Bernius et al., "Developmental Progress of Electroluminescent Polymeric Materials  
11 and Devices," Proceedings of SPIE Conference on Organic Light Emitting Materials  
12 and Devices III, Denver, Colorado, July 1999, Volume 3797, p. 129).

13 Another class of organic electroluminescent materials that can be utilized in the  
14 luminescent region includes, but is not limited to, the metal oxinoid compounds as  
15 disclosed in U.S. Patents 4,539,507; 5,151,629; 5,150,006; 5,141,671 and 5,846,666,  
16 each incorporated herein by reference in its entirety. Illustrative examples include  
17 tris(8-hydroxyquinolate) aluminum (AlQ3), which is one preferred example, and  
18 bis(8-hydroxyquinolato)-(4-phenylphenolato) aluminum (BALq) which is another  
19 preferred example. Other examples of this class of materials include tris(8-  
20 hydroxyquinolate) gallium, bis(8-hydroxyquinolate) magnesium, bis(8-  
21 hydroxyquinolate) zinc, tris(5-methyl-8-hydroxyquinolate) aluminum, tris(7-  
22 propyl-8-quinolinolato) aluminum, bis[benzo{f}-8-quinolate]zinc, bis(10-  
23 hydroxybenzo[h]quinolate) beryllium, and the like, and metal thioxinoid compounds  
24 disclosed in U.S. Patent 5,846,666 (which is incorporated herein by reference in its  
25 entirety), such as metal thioxinoid compounds of bis(8-quinolinethiolato)zinc, bis(8-  
26 quinolinethiolato)cadmium, tris(8-quinolinethiolato)gallium, tris(8-  
27 quinolinethiolato)indium, bis(5-methylquinolinethiolato)zinc, tris(5-  
28 methylquinolinethiolato)gallium, tris(5-methylquinolinethiolato)indium, bis(5-  
29 methylquinolinethiolato)cadmium, bis(3-methylquinolinethiolato)cadmium, bis(5-  
30 methylquinolinethiolato)zinc, bis[benzo{f}-8-quinolinethiolato]zinc, bis[3-  
31 methylbenzo{f}-8-quinolinethiolato]zinc, bis[3,7-dimethylbenzo{f}-8-  
32 quinolinethiolato]zinc, and the like. Preferred materials are bis(8-  
33 quinolinethiolato)zinc, bis(8-quinolinethiolato)cadmium, tris(8-  
34 quinolinethiolato)gallium, tris(8-quinolinethiolato)indium and bis[benzo{f}-8-  
35 quinolinethiolato]zinc.

More specifically, a class of organic electroluminescent materials that can be used in the luminescent region comprises stilbene derivatives, such as those disclosed in U.S. Patent 5,516,577, incorporated herein by reference in its entirety. A preferred stilbene derivative is 4,4'-bis(2,2-diphenylvinyl)biphenyl.

Another class of suitable organic electroluminescent materials suitable for utilizing in the luminescent region is the oxadiazole metal chelates. These materials include bis[2-(2-hydroxyphenyl)-5-phenyl-1,3,4-oxadiazolato]zinc; bis[2-(2-hydroxyphenyl)-5-phenyl-1,3,4-oxadiazolato]beryllium; bis[2-(2-hydroxyphenyl)-5-(1-naphthyl)-1,3,4-oxadiazolato]zinc; bis[2-(2-hydroxyphenyl)-5-(1-naphthyl)-1,3,4-oxadiazolato]beryllium; bis[5-biphenyl-2-(2-hydroxyphenyl)-1,3,4-oxadiazolato]zinc; bis[5-biphenyl-2-(2-hydroxyphenyl)-1,3,4-oxadiazolato]beryllium; bis(2-hydroxyphenyl)-5-phenyl-1,3,4-oxadiazolato]lithium; bis[2-(2-hydroxyphenyl)-5-p-tolyl-1,3,4-oxadiazolato]zinc; bis[2-(2-hydroxyphenyl)-5-p-tolyl-1,3,4-oxadiazolato]beryllium; bis[5-(p-tert-butylphenyl)-2-(2-hydroxyphenyl)-1,3,4-oxadiazolato]zinc; bis[5-(p-tert-butylphenyl)-2-(2-hydroxyphenyl)-1,3,4-oxadiazolato]beryllium; bis[2-(2-hydroxyphenyl)-5-(3-fluorophenyl)-1,3,4-oxadiazolato]zinc; bis[2-(2-hydroxyphenyl)-5-(4-fluorophenyl)-1,3,4-oxadiazolato]zinc; bis[2-(2-hydroxyphenyl)-5-(4-fluorophenyl)-1,3,4-oxadiazolato]beryllium; bis[5-(4-chlorophenyl)-2-(2-hydroxyphenyl)-1,3,4-oxadiazolato]zinc; bis[2-(2-hydroxyphenyl)-5-(4-methoxyphenyl)-1,3,4-oxadiazolato]zinc; bis[2-(2-hydroxy-4-methylphenyl)-5-phenyl-1,3,4-oxadiazolato]zinc; bis[2- $\alpha$ -(2-hydroxynaphthyl)-5-phenyl-1,3,4-oxadiazolato]zinc; bis[2-(2-hydroxyphenyl)-5-p-pyridyl-1,3,4-oxadiazolato]zinc; bis[2-(2-hydroxyphenyl)-5-p-pyridyl-1,3,4-oxadiazolato]beryllium; bis[2-(2-hydroxyphenyl)-5-(2-thiophenyl)-1,3,4-oxadiazolato]zinc; bis[2-(2-hydroxyphenyl)-5-phenyl-1,3,4-thiadiazolato]zinc; bis[2-(2-hydroxyphenyl)-5-phenyl-1,3,4-thiadiazolato]beryllium; bis[2-(2-hydroxyphenyl)-5-(1-naphthyl)-1,3,4-thiadiazolato]zinc; and bis[2-(2-hydroxyphenyl)-5-(1-naphthyl)-1,3,4-thiadiazolato]beryllium, and the like; and the triazines including those disclosed in U.S. Patent 6,057,048, which is incorporated herein by reference in its entirety.

The luminescent region can further include from about 0.01 weight percent to about 25 weight percent of a luminescent material as a dopant. Examples of dopant materials that can be utilized in the luminescent region are fluorescent materials, such as coumarin, dicyanomethylene pyranes, polymethine, oxabenzanthrane, xanthene, pyrylium, carbostyl, perylene, and the like. Another preferred class of fluorescent

materials are quinacridone dyes. Illustrative examples of quinacridone dyes include quinacridone, 2-methylquinacridone, 2,9-dimethylquinacridone, 2-chloroquinacridone, 2-fluoroquinacridone, 1,2-benzoquinacridone, N,N'-dimethylquinacridone, N,N'-dimethyl-2-methylquinacridone, N,N'-dimethyl-2,9-dimethylquinacridone, N,N'-dimethyl-2-chloroquinacridone, N,N'-dimethyl-2-fluoroquinacridone, N,N'-dimethyl-1,2-benzoquinacridone, and the like as disclosed in U.S. Patents 5,227,252; 5,276,381 and 5,593,788, each incorporated herein by reference in its entirety. Another class of fluorescent materials that may be used is fused ring fluorescent dyes. Exemplary suitable fused ring fluorescent dyes include perylene, rubrene, anthracene, coronene, phenanthrene, pyrene and the like, as disclosed in U.S. Patent 3,172,862, which is incorporated herein by reference in its entirety. Also, fluorescent materials include butadienes, such as 1,4-diphenylbutadiene and tetraphenylbutadiene, and stilbenes, and the like, as disclosed in U.S. Patents 4,356,429 and 5,516,577, each incorporated herein by reference in its entirety. Other examples of fluorescent materials that can be used are those disclosed in U.S. Patent 5,601,903, which is incorporated herein by reference in its entirety.

Additionally, luminescent dopants that can be utilized in the luminescent region are the fluorescent dyes disclosed in U.S. Patent 5,935,720 (which is incorporated herein by reference in its entirety) such as 4-(dicyanomethylene)-2-*I-propyl*-6-(1,1,7,7-tetramethyljulolidyl-9-enyl)-4*H*-pyran (DCJTB); the lanthanide metal chelate complexes, such as for example, tris(acetylacetonato)(phenanthroline) terbium, tris(acetylacetonato)(phenanthroline) europium, and tris(thenoyl trisfluoroacetonato)(phenanthroline) europium, and those disclosed in Kido et al., "White light emitting organic electroluminescent device using lanthanide complexes," Jpn. J. Appl. Phys., Volume 35, pp. L394-L396 (1996), which is incorporated herein by reference in its entirety; and phosphorescent materials, such as organometallic compounds containing heavy metal atoms that lead to strong spin-orbit coupling, such as those disclosed in Baldo et.al., "Highly efficient organic phosphorescent emission from organic electroluminescent devices," Letters to Nature, Volume 395, pp. 151-154 (1998), which is incorporated herein by reference in its entirety. Preferred examples include 2,3,7,8,12,13,17,18-octaethyl-21*H*23*H*-phorphine platinum(II) (PtOEP) and *fac* tris(2-phenylpyridine)iridium (Ir(ppy)<sub>3</sub>).

The luminescent region can also include one or more materials with hole-transporting properties. Examples of hole-transporting materials that can be utilized in the luminescent region include polypyrrole, polyaniline, poly(phenylene vinylene),

polythiophene, polyarylamine as disclosed in U.S. Patent 5,728,801, which is incorporated herein by reference in its entirety, and their derivatives, and known semiconductive organic materials; porphyrin derivatives such as 1,10,15,20-tetraphenyl-21H,23H-porphyrin copper (II) disclosed in U.S. Patent 4,356,429, incorporated herein by reference in its entirety; copper phthalocyanine, copper tetramethyl phthalocyanine; zinc phthalocyanine; titanium oxide phthalocyanine; magnesium phthalocyanine; and the like

A specific class of hole transporting materials that can be utilized in the luminescent region are the aromatic tertiary amines such as those disclosed in U.S. Patent 4,539,507, which is incorporated herein by reference in its entirety. Suitable exemplary aromatic tertiary amines include, but are not limited to, bis(4-dimethylamino-2-methylphenyl)phenylmethane, N,N,N-tri(p-tolyl)amine, 1,1-bis(4-di-p-tolylaminophenyl)cyclohexane, 1,1-bis(4-di-p-tolylaminophenyl)-4-phenylcyclohexane, N,N'-diphenyl-N,N'-bis(3-methylphenyl)-1,1'-biphenyl-4,4'-diamine, N,N'-diphenyl-N,N'-bis(3-methylphenyl)-1,1'-biphenyl-4,4'-diamine, N,N'-diphenyl-N,N'-bis(4-methoxyphenyl)-1,1'-biphenyl-4,4'-diamine, N,N,N',N'-tetra-p-tolyl-1,1'-biphenyl-4,4'-diamine, N,N'-di-1-naphthyl-N,N'-diphenyl-1,1'-biphenyl-4,4'-diamine, mixtures thereof and the like. Another class of aromatic tertiary amines are polynuclear aromatic amines. Examples of these polynuclear aromatic amines include, but are not limited to, N,N-bis-[4'-(N-phenyl-N-m-tolylamino)-4-biphenyl]aniline; N,N-bis-[4'-(N-phenyl-N-m-tolylamino)-4-biphenyl]-m-toluidine; N,N-bis-[4'-(N-phenyl-N-m-tolylamino)-4-biphenyl]-p-toluidine; N,N-bis-[4'-(N-phenyl-N-p-tolylamino)-4-biphenyl]aniline; N,N-bis-[4'-(N-phenyl-N-p-tolylamino)-4-biphenyl]-m-toluidine; N,N-bis-[4'-(N-phenyl-N-p-tolylamino)-4-biphenyl]-p-toluidine; N,N-bis-[4'-(N-phenyl-N-p-chlorophenylamino)-4-biphenyl]-m-toluidine; N,N-bis-[4'-(N-phenyl-N-m-chlorophenylamino)-4-biphenyl]-m-toluidine; N,N-bis-[4'-(N-phenyl-N-m-chlorophenylamino)-4-biphenyl]-p-toluidine; N,N-bis-[4'-(N-phenyl-N-m-tolylamino)-4-biphenyl]-p-chloroaniline; N,N-bis-[4'-(N-phenyl-N-p-tolylamino)-4-biphenyl]-m-chloroaniline; N,N-bis-[4'-(N-phenyl-N-m-tolylamino)-4-biphenyl]-1-aminonaphthalene, mixtures thereof and the like; 4,4'-bis(9-carbazolyl)-1,1'-biphenyl compounds, such as 4,4'-bis(9-carbazolyl)-1,1'-biphenyl and 4,4'-bis(3-methyl-9-carbazolyl)-1,1'-biphenyl, and the like.

A specific class of the hole transporting materials that can be used in the luminescent region are the indolo-carabazoles, such as those disclosed in U.S. Patents 5,942,340 and 5,952,115, each incorporated herein by reference in its entirety, such as

1 5,11-di-naphthyl-5,11-dihydroindolo[3,2-b]carbazole, and 2,8-dimethyl-5,11-di-  
2 naphthyl-5,11-dihydroindolo[3,2-b]carbazole; N,N,N',N'-tetraarylbenzidines, wherein  
3 aryl may be selected from phenyl, m-tolyl, p-tolyl, m-methoxyphenyl, p-  
4 methoxyphenyl, 1-naphthyl, 2-naphthyl and the like. Illustrative examples of  
5 N,N,N',N'-tetraarylbenzidine are N,N'-di-1-naphthyl -N,N'- diphenyl-1,1'-biphenyl-4,4'-  
6 diamine, which is more preferred; N,N'-bis(3-methylphenyl) -N,N'- diphenyl-1,1'-  
7 biphenyl-4,4'-diamine; N,N'-bis(3-methoxyphenyl) -N,N'- diphenyl-1,1'-biphenyl-4,4'-  
8 diamine, and the like. Preferred hole transporting materials that can be used in the  
9 luminescent region are the naphthyl-substituted benzidine derivatives.

10 The luminescent region can also include one or more materials with electron  
11 transporting properties. An example of electron transporting materials that can be  
12 utilized in the luminescent region is polyfluorenes, such as poly(9,9-di-n-octylfluorene-  
13 2,7-diyl), poly(2,8-(6,7,12,12-tetraalkylindenofluorene) and copolymers containing  
14 fluorenes such as fluorene-amine copolymers, as disclosed in incorporated Bernius et  
15 al., Proceedings of SPIE Conference on Organic Light Emitting Materials and Devices  
16 III, Denver, Colorado, July 1999, Volume 3797, p. 129.

17 Other examples of electron transporting materials that can be utilized in the  
18 luminescent region can be selected from the metal oxinoid compounds, the oxadiazole  
19 metal chelate compounds, the triazine compounds and the stilbene compounds,  
20 examples of which have been described above in detail.

21 In embodiments where the luminescent region includes one or more hole  
22 transport material and/or one or more electron transport material in addition to the  
23 organic electroluminescent material(s), the organic electroluminescent material, the  
24 hole transport material(s), and/or the electron transport material(s) can be formed in  
25 separate regions, such as the OLEDs disclosed in U.S. Patents 4,539,507; 4,720,432  
26 and 4,769,292; or in the same region thus forming mixed regions of two or more  
27 materials, such as the OLEDs disclosed in U.S. Patent 6,130,001, and in U.S.  
28 Application Serial Nos. 09/357,551, filed on July 20, 1999; 09/606,670, filed on June  
29 30, 2000; and 09/770,159, filed on January 26, 2001. The disclosures of these patents  
30 and patent applications are incorporated herein by reference in their entirety.

31 The thickness of the luminescent region can vary for example, from about 10 Å  
32 to about 10,000 Å, typically from about 200 Å to about 2,000 Å, and particularly from  
33 about 500 Å to about 1,500 Å. In embodiments wherein the luminescent region  
34 includes two or more layers, the thickness of each layer can, for example, be from



1 about 10 Å to about 5,000 Å, typically from about 50 Å to about 2,000 Å, and  
2 particularly from about 100 Å to about 1,500 Å.

3 The organic light emitting device can be fabricated by sequentially forming the  
4 layers comprising the organic light emitting device on the substrate, using any suitable  
5 thin film forming technique, typically, spin coating or deposition by thermal  
6 evaporation in vacuum. In embodiments, the charge injecting layer, the light  
7 absorbing layer, and the optional buffer layer and metallic layer are deposited by  
8 thermal evaporation in vacuum.

9 More details about fabrication and operation of organic light emitting devices are  
10 disclosed, for example, in U.S. Patents 4,539,507 and 4,769,292, and in copending  
11 U.S. Applications No. 09/357,551, filed on July 20, 1999; No. 09/606,670, filed on  
12 June 30, 2000; and No. 09/770,159, filed on January 26, 2001, the disclosure of each  
13 patent and patent application being totally incorporated herein by reference.

14 The invention will now be described in detail with respect to specific preferred  
15 embodiments thereof, it being understood that these examples are intended to be  
16 illustrative only and the invention is not intended to be limited to the materials,  
17 conditions, or process parameters recited herein. All percentages and parts are by  
18 weight unless otherwise indicated.

## 20 EXAMPLE

21  
22 An inventive organic light emitting device according to the device structure of  
23 FIG. 1 was fabricated. The organic light emitting device was composed of in the  
24 sequence:

25 a substrate made of glass of about 1 mm thickness;

26 an anode composed of indium tin oxide of about 200 nm thickness;

27 a luminescent region composed of a hole transport layer of thickness about 60 nm  
28 coated on the anode, made of *N,N'*-di(naphthalene-1-yl)-*N,N'*-diphenyl-benzidine  
29 (NPB), and a luminescent electron transport layer, about 75 nm thick, coated on the  
30 hole transport layer made of tris (8-hydroxyquinoline) aluminum (AlQ3); and

31 a cathode including: (a) a substantially transparent electron injecting layer, about  
32 4 nm thick, made of Mg:Ag alloy (9:1 by volume), (b) a buffer layer, about 200 nm  
33 thick, made of SiO, (c) a light absorbing layer, about 500 nm thick, made of a black  
34 pigment material, Bis (1,8-Naphthimidazo) perinone, and (d) a metallic layer, about  
35 200 nm thick, made of Ag.

## COMPARATIVE EXAMPLE

A comparative organic light emitting device, similar to the inventive OLED of the Example but which included a conventional cathode, was fabricated and evaluated. The organic light emitting device was composed of in the sequence:

a substrate made of glass of thickness about 1 mm;

an anode composed of indium tin oxide, of thickness about 200 nm;

a luminescent region, composed of a hole transport layer of thickness about 60 nm coated on the anode, made of *N,N'*-di(naphthalene-1-yl)-*N,N'*-diphenyl-benzidine (NPB), and a luminescent electron transport layer, about 75 nm thick, coated on the hole transport layer made of tris (8-hydroxyquinoline) aluminum (AlQ3); and

a cathode including: (a) an electron injecting layer, about 120 nm thick, made of Mg:Ag alloy (9:1 by volume); and (b) a metallic layer, about 80 nm thick, made of Ag.

Both the inventive and comparative organic light emitting devices including the cathode layers were fabricated by thermal evaporation in vacuum (about  $5 \times 10^{-6}$  torr.) in the same pump down cycle.

Visual examination of the inventive and comparative organic light emitting devices revealed negligible reflectivity of the cathode of the inventive organic light emitting device, whereas the cathode of the comparative organic light emitting device was highly reflective of ambient illumination, giving it a mirror-like appearance.

When operated under 7 volts, emission from the inventive organic light emitting device demonstrated excellent visibility, regardless of the viewing angle, even when viewed under strong ambient illumination from a 200W flood light source placed about 15 cms apart from the device. On the other hand, emission from the comparative organic light emitting device, when operated under 7 volts, was almost invisible under the same ambient illumination conditions.

Other modifications of the present invention may occur to those skilled in the art based upon a reading of the present disclosure and these modifications are intended to be included within the scope of the present invention.